The TD-2 Microwave Radio Relay System

By A. A. ROETKEN, K. D. SMITH and R. W. FRIIS

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The TD-2 microwave radio relay system is a recent addition to the telephone plant facilities for long distance communication. It is designed to supplement the coaxial system and to provide greatly expanded facilities for nationwide transmission of broad-band signals such as television pictures or large groups of message circuits. The system makes use of many microwave repeaters located 25 to 30 miles apart in line-of-sight steps. The great variety and number of components which make up such a system require the engineering of all components to close tolerances. This paper describes the system in some detail from the standpoints of overall objectives, component designs to meet such objectives and facilities for the maintenance of overall performance.

I. Introduction

SUPER-HIGH or microwave frequencies began to attract the interest of communication research engineers during the late '30s. The practical application of microwaves to commercial communication circuits was delayed by the outbreak of World War II, but the microwave techniques which had already been developed were employed to advantage in the prosecution of the war. The concentrated development effort and mass production of microwave equipment for military applications greatly expanded the engineering knowledge and production skill in this relatively new communications field. After termination of the war, it was possible again to devote the necessary development effort toward application of microwave techniques to commercial purposes. In the Bell System this effort was applied to the development and construction of a long-haul radio relay system.

A broad-band multi-channel radio relay system now connecting some of the main communication centers of the United States, as shown in Fig. 1, represents the combined efforts of a Bell System team since 1945.[1] This chain of stations carrying hundreds of message circuits or a television picture on each broad-band channel, in giant 25 to 30-mile strides across the country, has opened up a new radio field. The first step was the development of an experimental system placed in service in November 1947 between New York and Boston.[2] Upon the successful completion of this project objectives were established for a system, which is called the TD-2 Radio System, capable of extension to at least 4000 miles with upwards of 125 repeaters.

The TD-2 Radio System provides no new types of service but will supplement existing facilities such as the coaxial system. Therefore, TD-2 must provide comparable reliability, economy and quality of service. It is

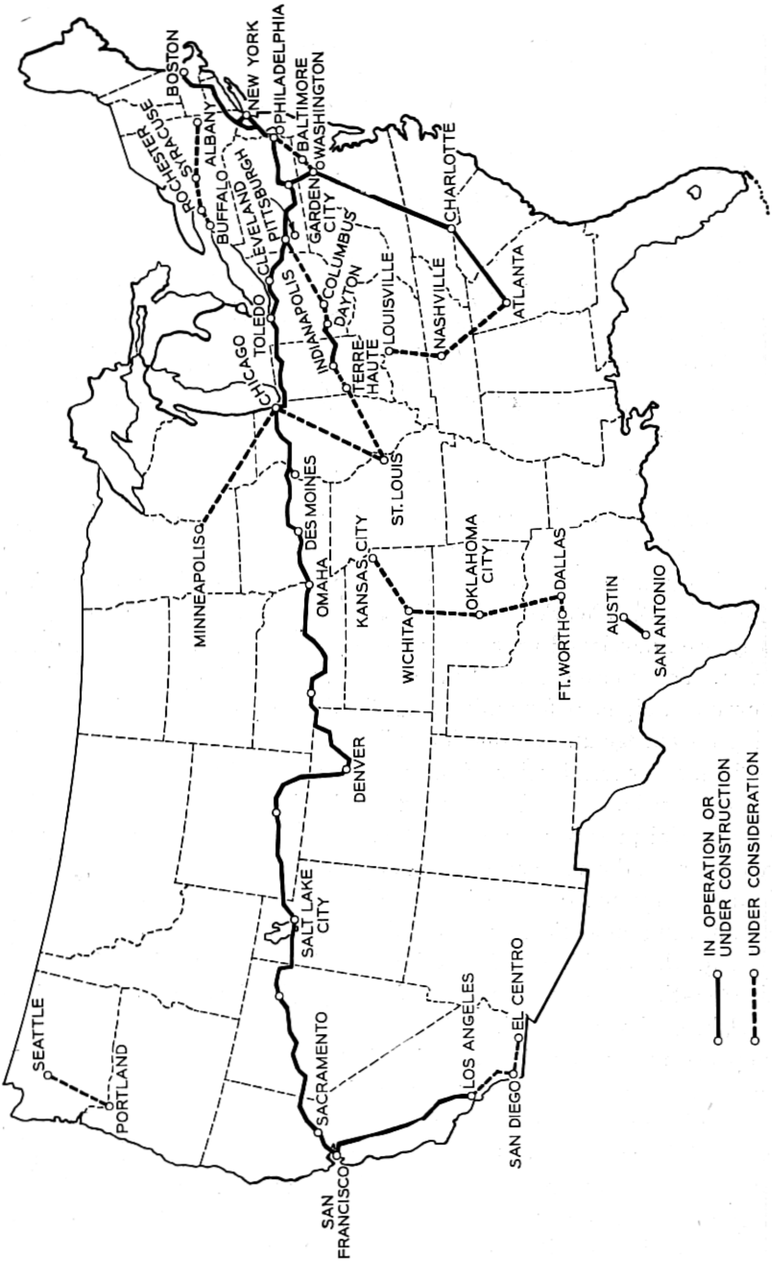

Fig. 1—TD microwave radio relay routes.

contemplated that by the end of 1951 there will be over 20,000 broad-band channel miles of radio relay in operation in the Bell System. Of this, about two-thirds will be used for television service and one-third to provide over 600,000 circuit miles of telephone circuits.

II. TD-2 System—General

A radio relay system designed for long distances involves many problems new to radio but not new to long distance wire circuits. These problems are chiefly those of systems engineering to close transmission tolerances be-

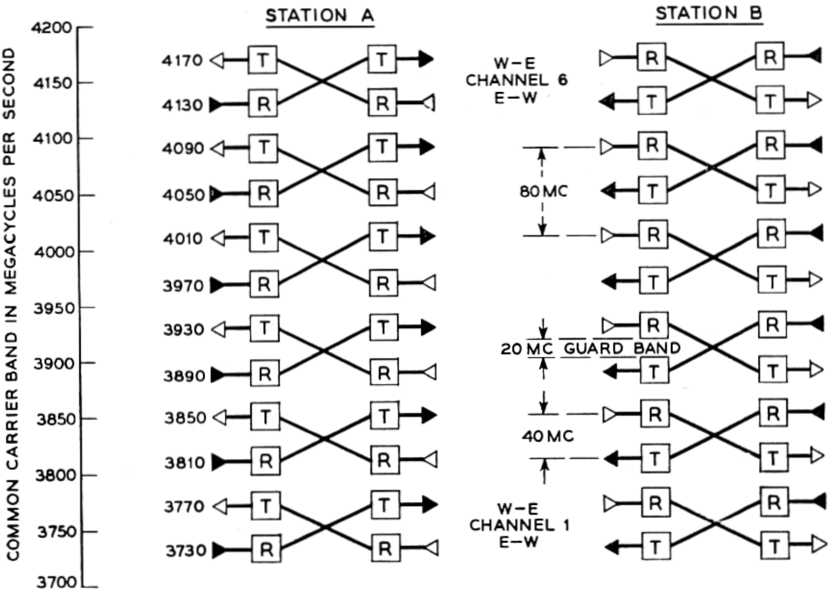

Fig. 2—TD-2 radio frequency plan.

cause of the many repeaters in tandem. To insure satisfactory systems operation, the transmission characteristics must remain stable over long periods of time to permit unattended operation. A reliable power plant and an alarm system are essential parts of the radio system.

A. *Description*

The TD-2 Radio System utilizes frequency modulation and provides twelve broad-band channels, six in each direction, spaced 40 megacycles apart in the 3700–4200 megacycle common carrier band. A frequency assignment chart is shown in Fig. 2 and a systems block diagram in Fig. 3. Two broad-band channels in opposite directions provide a two-way message

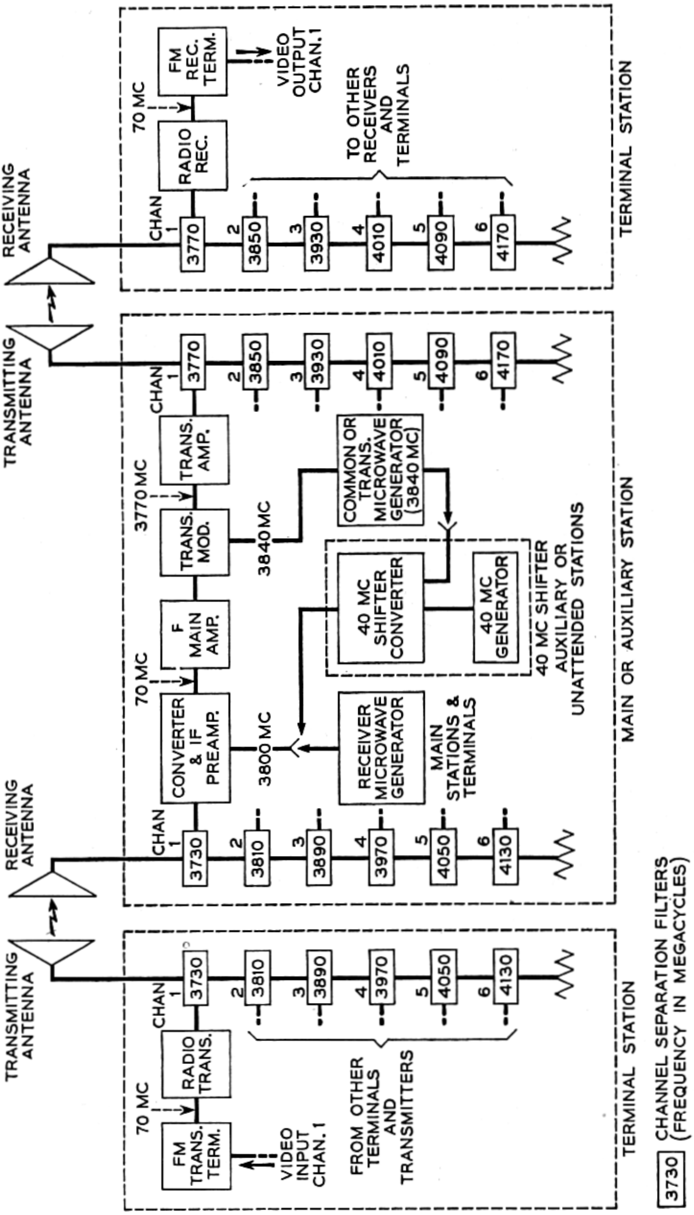

Fig 3—Radio system block diagram.

system having a capacity of hundreds of 4 kc message circuits. Alternately each of these broad-band channels can be used to provide a 4-megacycle video circuit of the kind required for present day black and white television or they may be used to provide broader band television circuits if the need for such circuits develops. The video or message input to a channel is frequency modulated on a 70-megacycle carrier, translated up to the microwave band, amplified and combined with the microwave output of other channels in the same direction. The combined output is carried through a single waveguide to a directive transmitting antenna[3] beamed toward the next station. At a repeater point the six-channel signal is received on a single antenna, separated by means of channel separation networks, and each channel converted to a 70-megacycle IF band for amplification. At a through repeater point this 70-megacycle IF signal again modulates the 4000-mega-

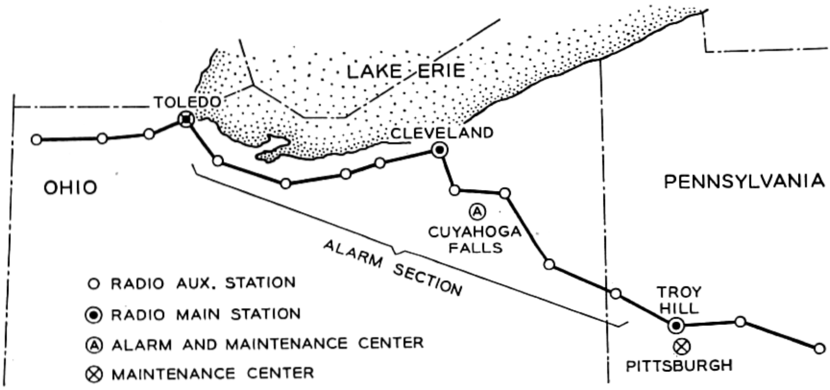

Fig. 4—Typical TD-2 route section.

cycle carrier, is amplified, added to the other channels in the same direction and delivered to the transmitting antenna. These are the simplified functions performed by the one-way radio repeater of the TD-2 System.

In order to feed a standard video or a multi-channel carrier signal into a TD-2 Radio System, an intermediate transmitter is required to frequency modulate these signals around a center frequency of 70 megacycles. This unit is known as the FM terminal transmitter. Likewise, at a receiving point an intermediate receiver is required to convert the 70-megacycle signal back to a video or carrier system signal. This unit is known as the FM terminal receiver.

A perspective of the system may be obtained from a typical route section as shown in Fig. 4. A long system is broken into sections by means of main repeater stations every few hundred miles. Auxiliary stations interconnect the main stations. From an operating standpoint, main stations differ from auxiliary stations primarily in that each channel is terminated in IF switching circuits. This permits the removal of a channel for maintenance, or the replacement of a section which has failed by a spare circuit, by patching or remote control of the IF switching circuits. An alarm center may also be identified in Fig. 4 as an attended office to which a maximum of twelve repeater stations are connected by wire or radio for the purpose of reporting abnormal conditions that exist. Maintenance personnel are dispatched to unattended stations from this point. Not all TD-2 units are repaired and maintained at the radio stations. Maintenance centers are established along the route to service these units which require more elaborate test facilities than are provided at the stations. This requires the furnishing of certain spare units at the individual repeater stations.

B. *Route Selection and Towers*

The interconnecting of two or more communication centers by a radio relay system presents many new problems in plant engineering. The selection of hundreds of mountain top sites to obtain line-of-sight transmission between stations, sites which are accessible to roads and power lines, sites which permit reasonable tower heights and which are an economic balance of these and other factors was a new challenge to the plant engineering force.[4] In brief, these were accomplished first by a detailed study of topographical and road maps, inspection of sites selected and finally the measurement of the transmission loss of the path.

The construction of towers several hundred feet high also involved new thinking by the building engineers.[5] The type of structure used on the New York-Chicago section of the TD-2 System was somewhat influenced by the availability of materials during 1948 and 1949. Concrete structures were used for this section of the system as shown in Fig. 5 with steel towers appearing on the Omaha to San Francisco section. Where steel towers are used, conventional type single-story buildings house the radio and associated equipment as shown in Fig. 6. Double antenna decks are provided on towers where branching radio routes are required.

III. TD-2 Radio Equipment

A. *Repeater—General*

The design of the TD-2 microwave repeater follows in principle that of its predecessor for the NewYork-Boston system.[2] Rapid advancement in the development of microwave vacuum tubes and other repeater components during the period from 1945 to 1947 led to a general improvement of repeater components for the TD-2 System. The realization in late 1947 of a

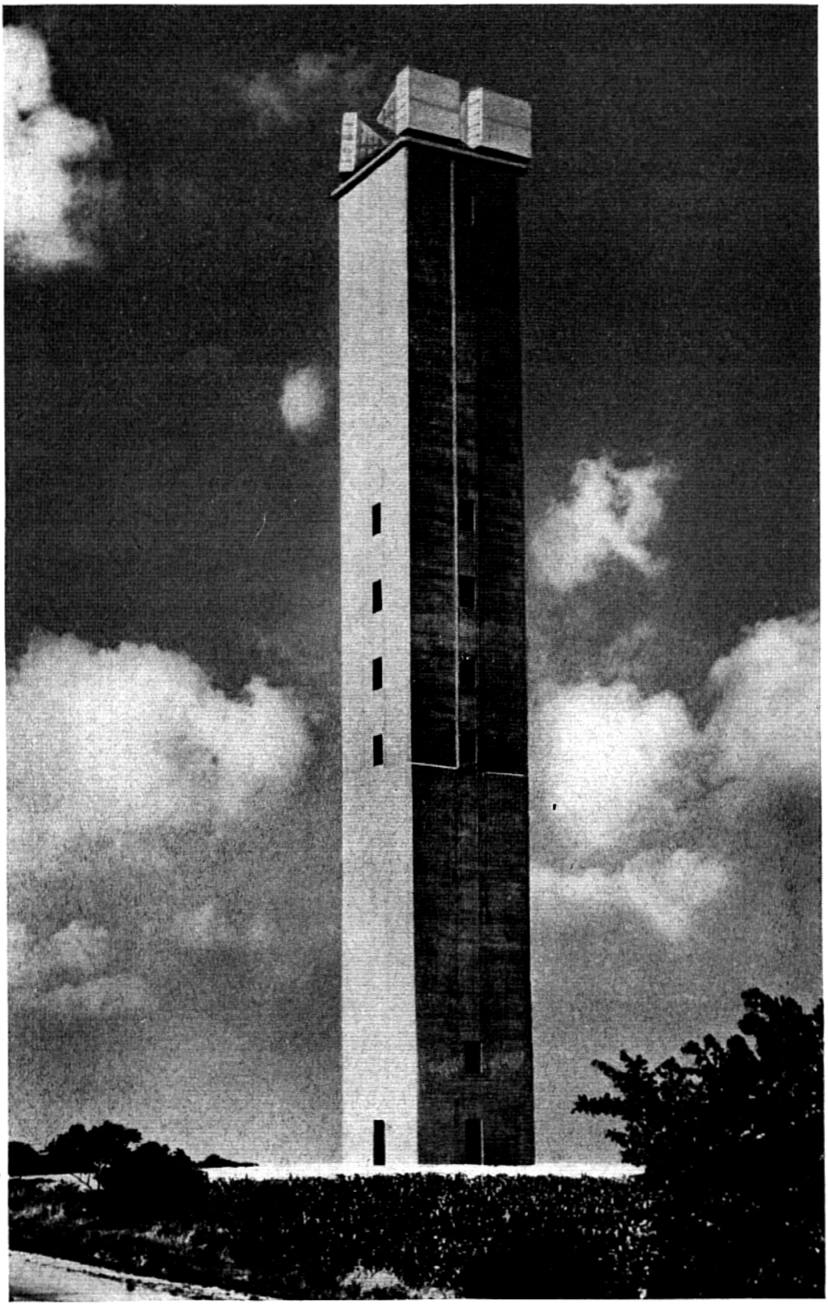

Fig. 5—190 foot concrete tower.

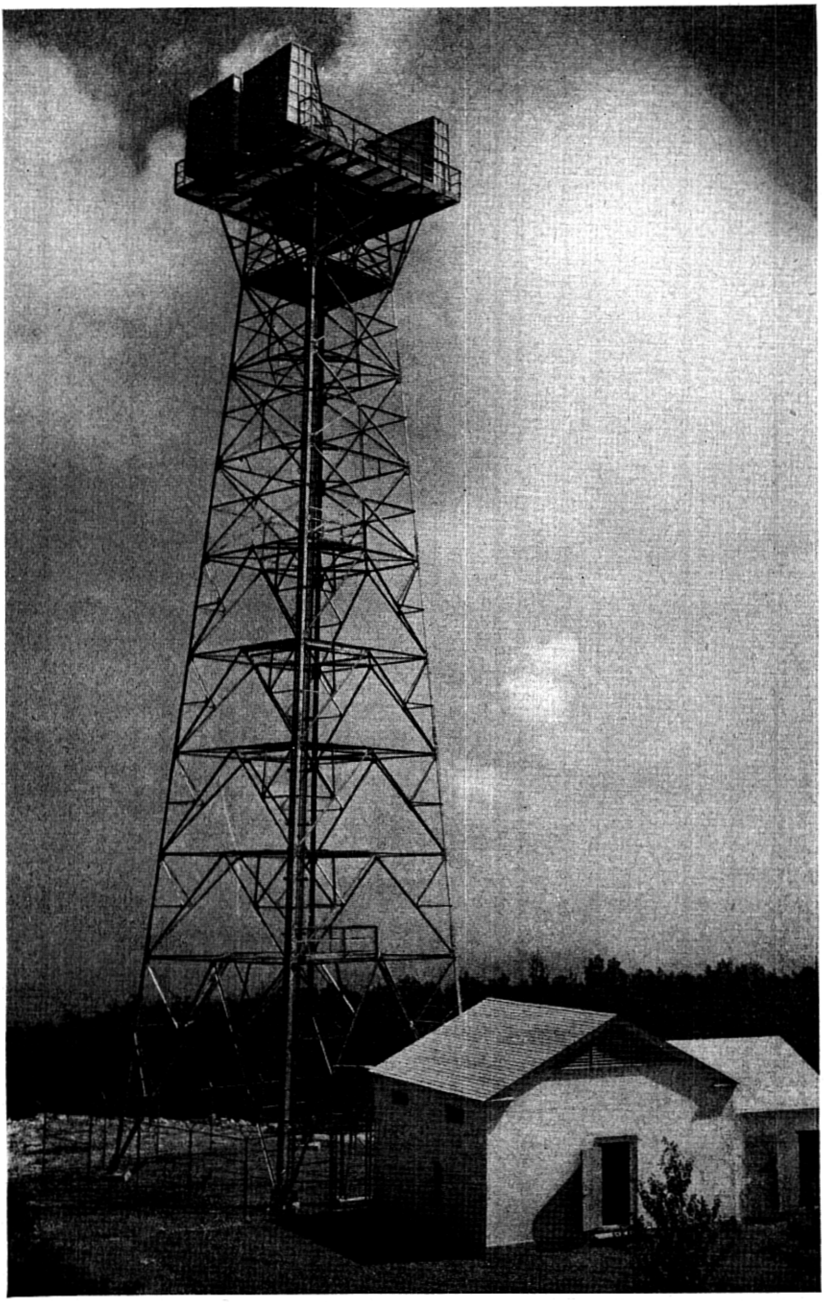

Fig. 6—125 foot steel tower.

practical triode amplifier for microwave application[6, 7] was instrumental in determining a pattern for redesign, for it suggested the possibility of greatly simplifying the repeater while at the same time providing wider transmission bandwidths at greatly improved efficiency. By replacing the high voltage klystron (velocity variation type) amplifiers of the early repeaters with the new low voltage triodes, it became practical to design the system for battery operation—an important step toward increasing the system's reliability as it removed regulated rectifier tubes from the vulnerable portion of the system and eliminated the problem of hits during switchover from commerical to standby primary power. In the TD-2 System, vacuum tube heaters are generally operated from a 12-volt battery through dropping resistors,

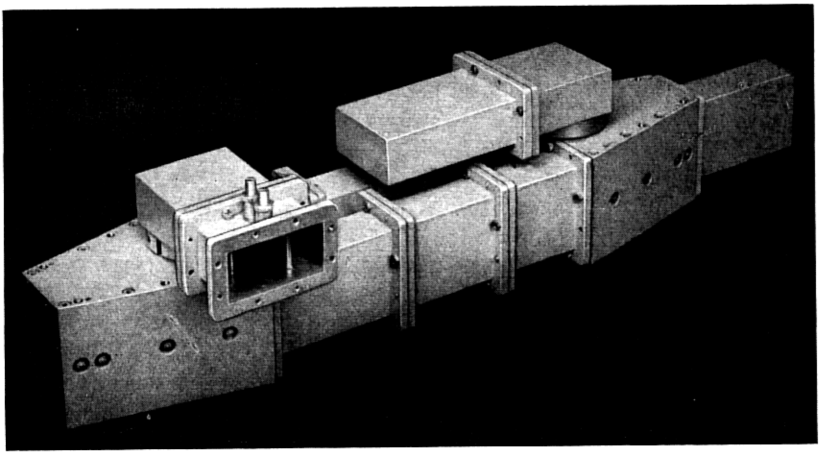

Fig. 7—Channel separation network.

thereby approximating constant heater power operation to increase tube life and reliability.

B. *Repeater Description*

A block diagram of a TD-2 repeater is shown in Fig. 3. An incoming microwave signal from a receiving antenna is selected by a channel separation network shown in Fig. 7. The signal is then combined in the receiver converter with energy from a beating oscillator source to provide an intermediate frequency signal band centered at 70 megacycles. Amplification, delay equalization and automatic gain control take place at the intermediate frequency of the radio receiver. In the transmitter this signal is combined in the transmitter modulator with a microwave source to provide a band offset 40 megacycles from the received frequency band. This signal is amplified and combined through transmitter channel separation networks with signals from other channels for transmission through a common antenna. The 40-megacycle shift from receiving to transmitting frequencies is introduced in order to reduce the effect of crosstalk between transmitting and receiving antennas.

Main and auxiliary station repeaters differ in the following respects: An auxiliary repeater simply receives a particular channel signal, amplifies and transmits it to the next station. Here a common beating oscillator source for the transmitter and receiver, together with a stable 40-megacycle shifter, results in a systems frequency stability, for auxiliary stations alone, which is dependent only upon the stability of the 40-megacycle oscillator.[2] This feature cannot be used in the repeaters of a main station since each radio section between main stations must be independent of other sections for switching, branching, maintenance and terminating purposes. Here it is necessary to provide an independent oscillator source for each modulation process. In such an arrangement, errors in frequency add throughout the system and, therefore, the individual stability requirements for the oscillators are severe. In the TD-2 System this frequency stability is obtained by the use of a crystal controlled oscillator and harmonic generators. Two such microwave generators with temperature controlled crystals are used in each repeater bay at main stations, while one microwave generator and a 40-megacycle oscillator and shifter unit are used in each auxiliary station repeater.

A repeater bay using a 9-foot cable duct type framework is shown in Fig. 8. The top half of the bay contains the components which comprise the signal path through the repeater. These are the channel separation filters, image suppression filter,

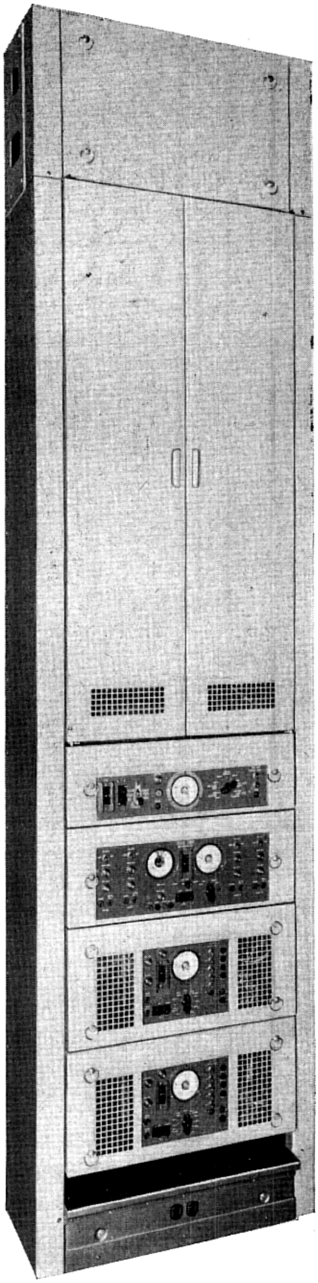

Fig. 8a

Fig. 8—Repeater bay.

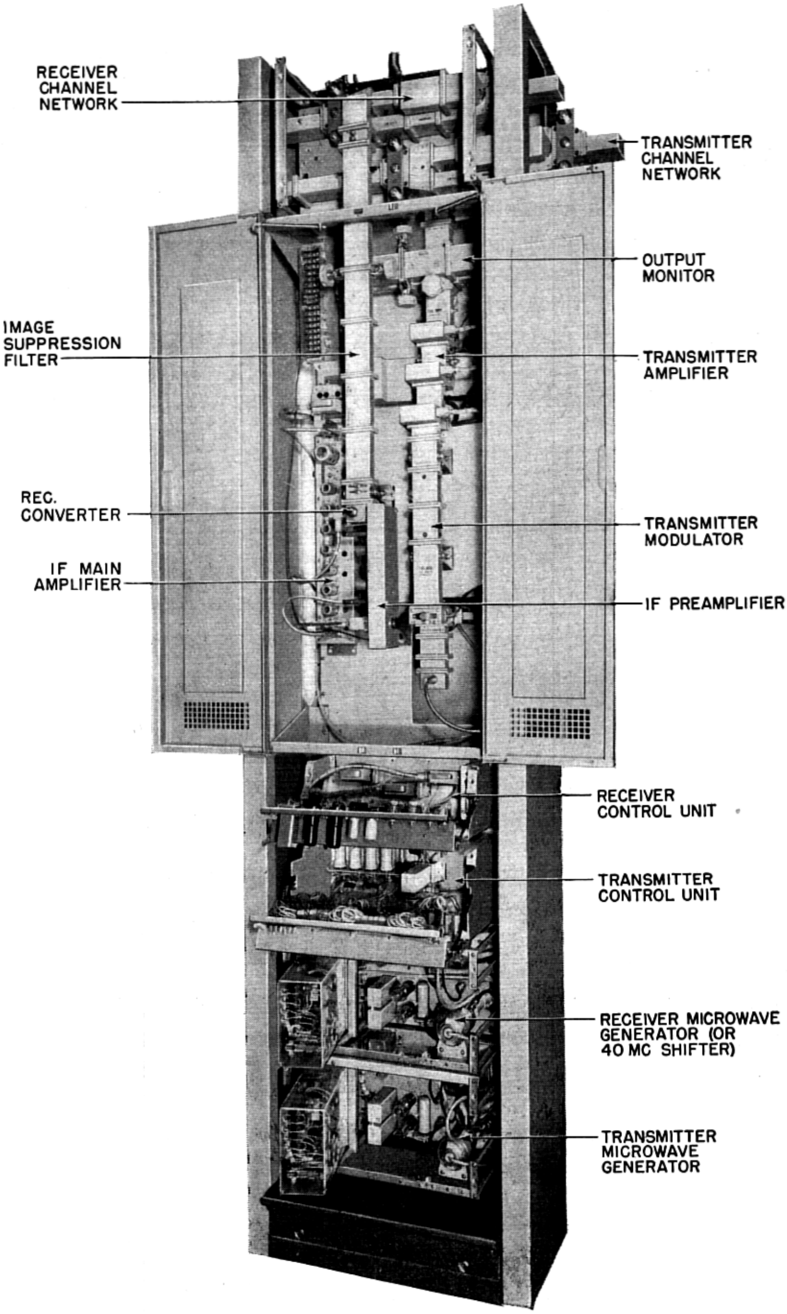
RECEIVER CHANNEL NETWORK
TRANSMITTER CHANNEL NETWORK
OUTPUT MONITOR
IMAGE SUPPRESSION FILTER
TRANSMITTER AMPLIFIER
REC. CONVERTER
TRANSMITTER MODULATOR
IF MAIN AMPLIFIER
IF PREAMPLIFIER
RECEIVER CONTROL UNIT
TRANSMITTER CONTROL UNIT
RECEIVER MICROWAVE GENERATOR (OR 40 MC SHIFTER)
TRANSMITTER MICROWAVE GENERATOR

Fig. 8b

receiving converter, IF preamplifier, delay equalizer, IF main amplifier, transmitting modulator and transmitting amplifier. The lower half of the bay contains four 19-inch wide oscillator and control units. These units, in the case of a main station repeater, are two microwave generators, a receiver control unit and a transmitter control unit. In the case of an auxiliary repeater, one of the microwave generators is replaced by a panel containing a 40-megacycle oscillator and shifter unit. All connections to the units of the bay are made by means of plugs and jacks for easy servicing.

A repeater receives a frequency modulated microwave signal at a normal level of about −38 dbm and transmits it at +27 dbm. Upward fades of 5 db and downward fades of 25 db are compensated to within about 1 db by automatic volume control action within the repeater. The amplitude characteristic is maintained flat to within 0.2 db over a 20-megacycle band.

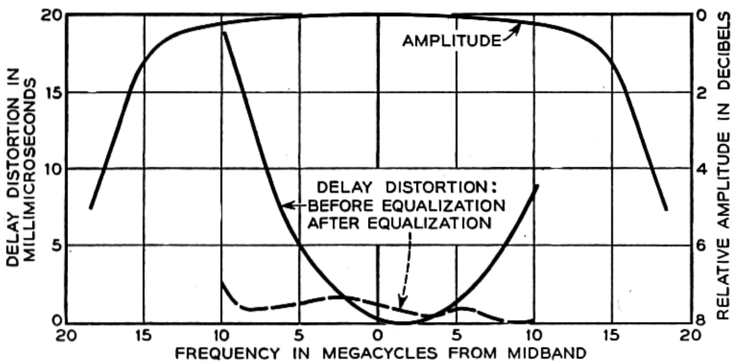

Fig. 9—Delay distortion & amplitude characteristics.

The amplitude and delay distortion characteristics of a repeater bay with and without delay equalization are shown in Fig. 9.

C. *Radio Receiver*

A channel separation network, as shown in Fig. 7, is required for each receiving channel. The network separates a particular channel from the six incoming 20-megacycle bandwidth channels for individual amplification and equalization in the repeater. It consists of two hybrid junctions and two band reflection filters which are tuned to the frequency band to be separated. An incoming signal is split into two parallel paths in passing through the first hybrid. A reflection filter in each of these paths returns the energy of the channel to be dropped to the first hybrid. By making the electrical path lengths from hybrid to filters differ by $\frac{1}{4}$ wavelength at the frequency of the channel to be dropped, the reflected signals are in phase opposition at the hybrid and this results in transmission of the total signal energy through the fourth arm of the hybrid and into the receiving converter. The reflection filters are transparent to frequencies outside the desired 20-megacycle band. These frequencies are recombined in the second hybrid for transmission to the following channel separation networks.

An image suppression filter is located in the waveguide just ahead of the receiving converter. Its purpose is twofold: first, to provide discrimination against interfering signals which are the intermediate frequency image of the desired signal; and, second, to provide a critically spaced reflection of a beating oscillator component from the converter for control of the converter intermediate frequency output impedance.

The receiving converter is of the balanced crystal type in which the two crystals are mounted in a hybrid junction assembly. The signal input connection is by waveguide and the oscillator input connection is by coaxial line. An unbalanced output at intermediate frequency without the use of a balanced to unbalanced transformer is obtained by reversal of the polarity of one crystal relative to the other, permitting a parallel output connection. The 405A varistor unit, having symmetrical terminal design, was developed for this application. The preamplifier utilizes two 417A grounded grid triodes and has a gain of approximately 12 db. Its transmission band is centered at 70 megacycles and is flat to within 0.1 db over a 22-megacycle bandwidth. The converter-preamplifier has a net gain of approximately 6 db. The output of the preamplifier is coaxially connected through a delay equalizer to the input of the main IF amplifier.

The main IF amplifier shown in Fig. 10 has input and output impedances of 75 ohms and approximately 65 db gain. It consists of eight stages of amplification, the first being a 417A grounded grid triode followed by six stages of 404A pentodes and a 418A tetrode output stage. The input, output and interstage networks are all of the double-tuned impedance-matched type except the network between the sixth 404A pentode and the 418A output tetrode which is triple tuned and mismatched. Tuning of the triple-tuned network provides for adjustment of the over-all transmission band shape. Automatic gain control operating upon the grids of the first five pentode stages maintains the output power to within 1 db of a selected value between +4 dbm and +10 dbm for a 30 db range in input power. A low level bridging tap is available at the output of the main IF amplifier.

D. *Radio Transmitter*

The transmitter modulator consists of a 416A microwave triode mounted in a structure which provides a resonant cavity between cathode and grid and another between plate and grid. This cavity structure is used in both

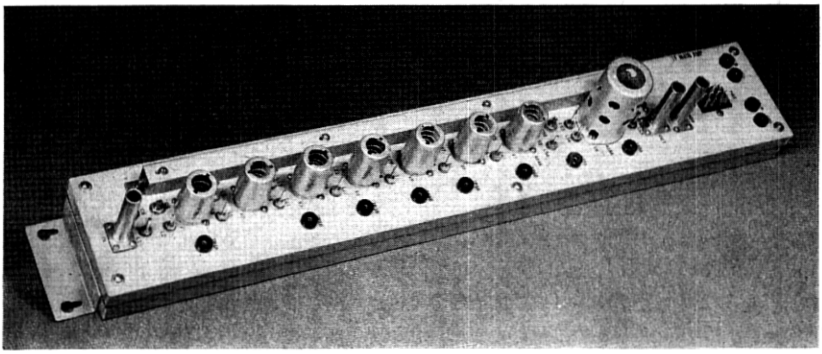

Fig. 10—Main IF amplifier.

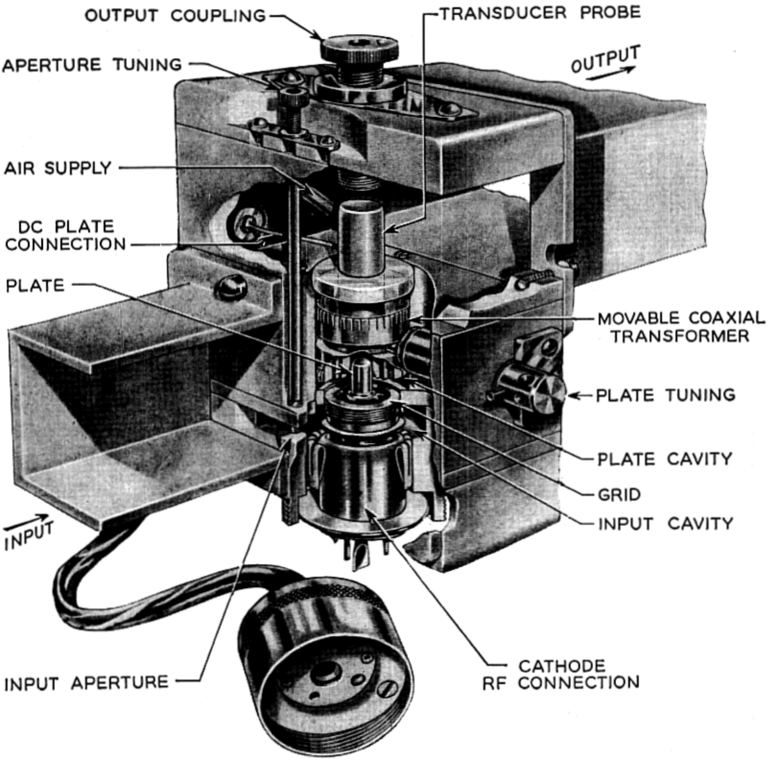

Fig. 11—416A tube cavity.

the modulator and the transmitter amplifiers and can best be described with the aid of a sectional view as shown in Fig. 11. The tube screws into the cavity with the grid grounded directly to the body of the structure. The cathode of the tube is connected through an internal by-pass condenser to another part of the structure such that a cavity is formed around the tube between grid and cathode. An iris or aperture which is capacity tuned by a screw provides a means for coupling to the input waveguide. A coaxial cavity is formed around the plate which is tuned to the desired frequency by the movable coaxial transformer. The transformer couples the plate cavity to the transducer probe where the signal energy is transferred to the output waveguide.

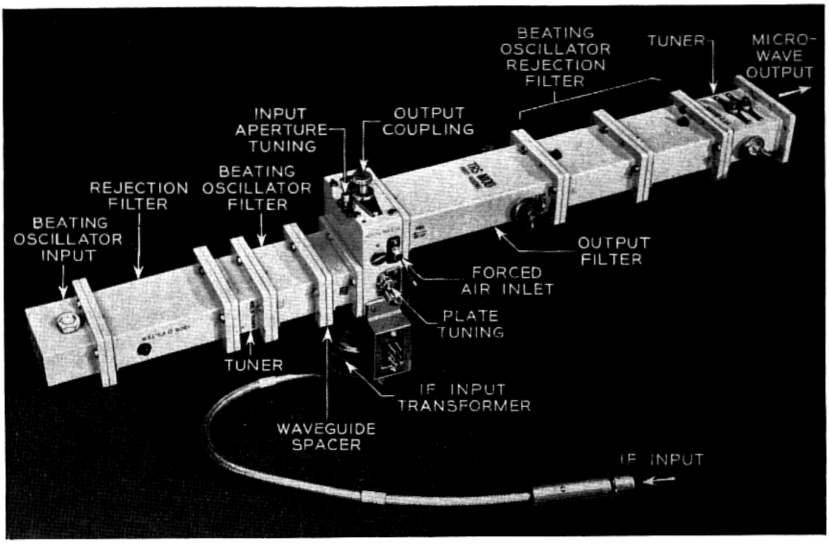

Fig. 12—Transmitter modulator.

The transmitter modulator is shown in Fig. 12. The oscillator power is applied to the cathode grid cavity through a tuner, a bandpass filter and a waveguide spacer. The IF power is applied between cathode and grid through a network which is mounted within a cylindrical compartment around the tube socket. The desired output sideband of the modulator is selected by a bandpass filter. Following this filter is a tuner unit which provides a means for adjusting the output impedance for a match with the following amplifier. A conversion gain of 9 db is realized in the process of shifting the IF frequency to the microwave band.

The modulator assembly is directly connected to the input of the transmitter amplifier, as may be seen in Fig. 8. An amplifier shown in Fig. 13 consists of three stages of 416A triodes mounted in cavity structures as described above. The three stages are connected together in cascade through waveguide spacers and reactance tuners of such dimensions that the joining of each output cavity with the following input cavity (or filter section in the case of the output stage) forms a double-tuned critically coupled transformer. A flat over-all transmission characteristic is thereby obtained which is about 20 megacycles wide between points 0.1 db down. While capable of greater gain, the amplifier is adjusted to a gain of 18 db at an output power level of 0.5 watt. A double directional coupler in the waveguide between the transmitting amplifier and the transmitter channel separation filter provides monitoring and output alarm signals.

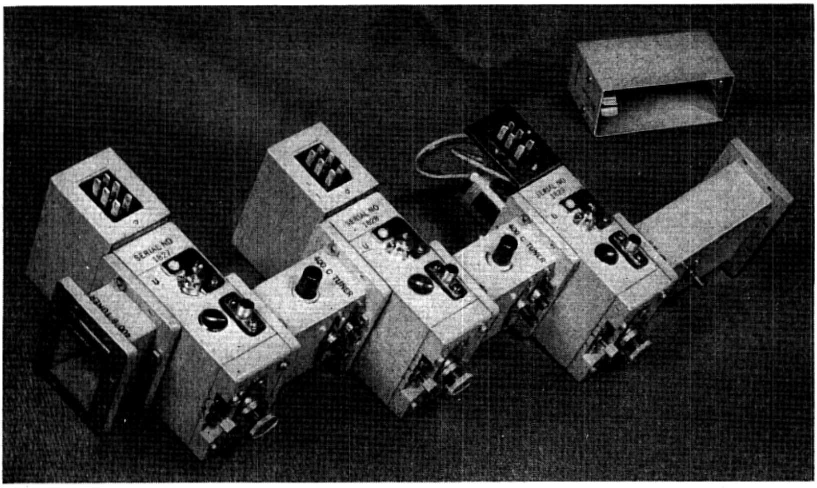

Fig. 13—Transmitter amplifier.

E. *Microwave Sources and Control Circuits*

The receiver control unit may be seen in Fig. 8. It contains a stabilized d-c amplifier for IF automatic gain control and level adjustments, and testing facilities for checking the performance of the receiver. The control unit also contains power controls and protection devices for the plate and filament circuits. The transmitter control unit contains controls for the application of power and bias to the transmitter and a means for metering various circuits.

The microwave generator, which furnishes about 200 milliwatts of beating oscillator power for the transmitter and receiver, is a stable microwave frequency source developed by harmonic generation from a quartz crystal in the vicinity of 18 megacycles. The multiplication takes place in six harmonic generator stages, three doublers and three triplers. Only a few milliwatts of output power is required where the generator is used for the receiver beating oscillator alone, as in main stations or terminals. Here the final multiplier is operated as a sextupler, thereby permitting the elimination of the penultimate stage. At an auxiliary repeater, the receiving beating oscillator source is obtained from a 40-megacycle shifter converter, one input of which is from a part of the microwave generator output, and the other is from a crystal controlled 40-megacycle generator.

F. *Transmitter-Receiver Interconnections*

At auxiliary stations the IF output of the receiver is connected by a short coaxial line and 5 db resistance pad directly to the transmitting modulator in the same bay. This resistance pad is used as an impedance matching aid.

At main repeater stations the IF receiver output and the transmitter input are carried in coaxial lines to IF patching and switching equipment. With 30 to 60 feet of coaxial line between the receiver and transmitter, impedance match requirements are more severe than for short coaxial line connections. Here, a 6 db resistance pad is connected in the output line of the receiver and a 3 db resistance pad and buffer amplifier are connected in the input line of the transmitter modulator. The buffer amplifier consists of a single stage using a 418A tetrode and its gain may be set manually to provide -1 dbm to $+5$ dbm of signal power into the transmitter modulator as required. The bandwidth of the amplifier is approximately 20 megacycles and is sloped in such a manner as to approximately compensate for the small variation of loss over the band in the patching coaxial lines.

G. *IF Switching**

IF switching circuits are provided at terminals and main repeater points to facilitate maintenance operations as well as to provide flexibility for the changing requirements of network distribution. These switching and distributing operations are obtained by the use of unity gain amplifiers which are designated IF switching amplifiers and IF distributing amplifiers.

An IF switching amplifier functions as a single-pole double-throw switch for connection between intermediate frequency circuits of 75-ohm impedance. It has two input networks, each connected to a grid of a 404A pentode. The plates of the two tubes are connected in parallel to the output. Transmission through one or the other of the tubes is prevented by the application of a high negative grid bias to that tube. Switching the bias from one tube to the other thus permits the selection of either input signal. In most

* Prepared by T. R. D. Collins.

applications of the switching amplifier, signaling facilities are provided so that the switching operation can be controlled remotely.

An IF distributing amplifier provides three outputs from a single input, all at 75-ohm impedance. It consists of four 404A pentodes, the plate of one tube being connected to the grids of the other three tubes through an interstage network. Individual networks from the three output stages provide the desired distributing branches which are well isolated from each other electrically.

Switching and distributing amplifiers and a mounting framework are shown in Fig. 14. The two amplifiers have the same physical size and as many as five such units may be mounted in a frame on a plug-in basis. A number of such mounting frames are grouped and mounted on duct type bays to meet the needs of each switching and distributing location. Jack

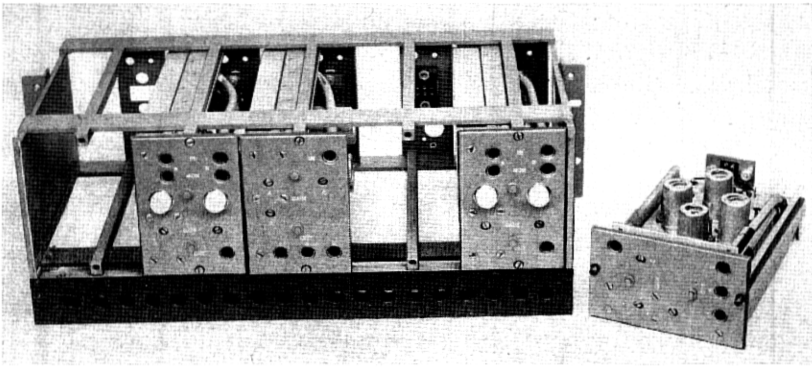

Fig. 14—Switching and distribution amplifiers.

fields associated with the mounting frames terminate the interbay coaxial trunks through which the switching and distributing connections are made.

Various combinations of switching and distributing amplifiers perform a large variety of interconnection functions within the system. Figure 15 indicates how these amplifiers may be used to replace a circuit which has failed by a spare circuit. At a transmitting terminal, the regular and spare channels may be paralleled. If a transmission failure occurs in channel 1 at one of the auxiliary repeater stations east of the main station, the failure of this channel is noted at the end of the system and service is switched to the spare channel 2. Since channel 1 is good except for the break east of the main station, the remote control for the switching amplifier in channel 1 is operated to switch output A of the channel 2 distributing amplifier to channel 1 radio transmitter. Thus channel 1 is connected in parallel with channel 2 at this station and both a regular and a spare circuit are now available at succeeding stations.

H. *Automatic IF Switching**

At present IF switching is handled on a manual basis by attendants at the main stations or on a remote control basis over the order wire facilities. This type of switching is satisfactory for maintenance purposes but obviously is not fast enough to avoid a circuit interruption in replacing a circuit which has failed. The reliability of wire circuits will be difficult to meet in a long radio relay system without standby facilities because of vacuum tube failures and fading. Work is now under way to develop automatic IF switching facilities which will detect instantaneously a circuit

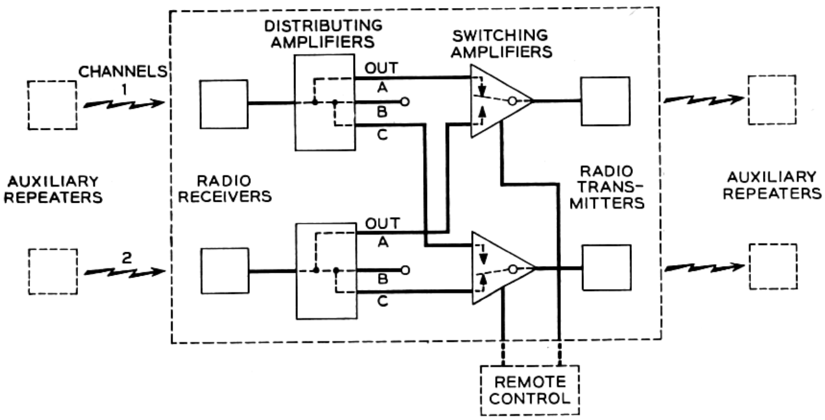

Fig. 15—IF switching and distributing amplifier. Interconnection diagram.

failure or an increase in noise on a radio channel and switch in a spare circuit for the poor section without circuit interruption. Fading data indicate that most deep fades which go beyond the range of the AGC circuit are of the selective type. Thus switching to a spare channel will provide frequency diversity advantages. With automatic switching it is believed the TD-2 System circuit outage time will not exceed that of wire circuits.

I. *Television Monitoring*

Visual monitoring facilities are provided at terminal and main repeater stations for observing circuit performance. Auxiliary repeater stations may also be so equipped in special cases. At transmitting or receiving terminals, monitoring connections are bridged to the video cables which run to operat-

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ing centers. The equipment units which make up the monitoring facilities are an auxiliary IF amplifier, an FM receiver, a video amplifier and a video monitor. A combination of these units is assembled in a bay to fit the needs of each monitoring location.

IV. FM Terminal Equipment

A. *General*

The TD-2 System will transmit a standard RMA black and white television signal or a band of message channels built up on a frequency division basis as provided by the coaxial cable message terminals. The FM terminal transmitter converts either of these signals to a frequency-modulated signal centered at 70 megacycles for application to the radio transmitter. The FM terminal receiver recovers the television or carrier signal from a frequency-modulated 70-megacycle signal. Thus the FM terminal equipment provides the connecting links between the TD-2 radio equipment and other facilities.

In a long system it may be necessary to bring the radio signal down to voice and back up to radio frequency many times in order to add and drop message groups. Each such process will require FM receiving and transmitting terminal equipment which consequently establishes severe linearity requirements for this equipment. An objective in the development of the terminals was to meet long haul systems performance requirements with sixteen pairs of terminals in tandem.

B. *FM Transmitter*

A functional diagram of the FM terminal transmitter is shown in Fig. 16. It accepts a signal from an unbalanced 75-ohm line and delivers an FM signal centered at 70 megacycles to the radio transmitter. The input level may be adjusted from 0.2 volt to 2.5 volts peak-to-peak with an output level of 13 dbm at an impedance of 75 ohms. For television transmission with a ± 4 megacycle swing the tips of the synchronizing pulses are at 74 megacycles and the picture white at 66 megacycles. For message service the nominal deviation is centered about 70 megacycles. For television transmission the output is automatically clamped to a predetermined frequency during each synchronizing pulse. These differences in operation are described in more detail below.

1. *Description*

The input signal to the FM transmitter is applied through an adjustable attenuator to a video amplifier consisting of two similar three-stage feedback amplifiers in tandem which have a combined gain of 42 db. The video amplifier output is applied to the repeller of a deviation oscillator described below.

A microwave heterodyne method of generating a 70-megacycle FM signal was selected because it was found possible to design a highly linear deviator in the microwave region. It also allows separate tests to be made of the transmitter and receiver linearity and thus facilitates maintenance.

A reflex klystron oscillator may be frequency-modulated by superimposing a modulating signal on the repeller d-c voltage. The rate of frequency change with change of repeller voltage passes through a minimum near the

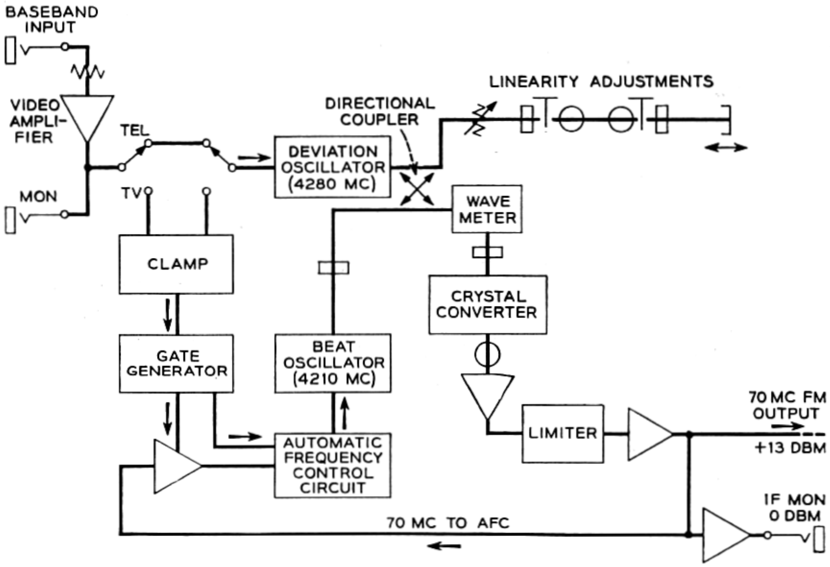


Fig. 16—Block diagram of FM terminal transmitter.

point of maximum power output. At a deviation of ±4 megacycles, the difference in FM sensitivity over the 8-megacycle swing would normally be sufficient to produce intolerable distortion. However, the operating frequency of a reflex oscillator is subject to modification by the load impedance seen by the oscillator. This effect is commonly called "pulling." In the deviation oscillator, this effect is made use of to provide deviation linearity over a range of more than 10 megacycles. The load circuit for the 4280-megacycle deviation oscillator consists of a variable attentuator, a short length of line, and a variable position short circuit. Adjustments of these two variables allows complete control of the reactance seen at the output of the deviation oscillator. The length of circuit to the movable short is so chosen (about 35 inches) to provide the optimum rate of change of reactance with frequency. At optimum adjustment, the reactive component of the load pulls the frequency of the generator by just the amount necessary to straighten out the deviation curve. The deviation sensitivity is at the same time increased about 25%, which reduces the required video driving voltage.

A portion of the output signal of the deviation oscillator is fed through a directional coupler to a crystal microwave converter where it is mixed with a 4210-megacycle signal from another klystron to produce a 70-megacycle FM signal. The microwave output from the deviation oscillator is about 50 milliwatts, and after losses in the directional coupler and converter about one milliwatt of 70-megacycle FM output is available. This signal is amplified in a broad-band limiter-amplifier for application directly to the radio transmitter or indirectly through appropriate switching circuits.

2. *Clamper and AFC Circuit*

For television transmission the voltage supplied to the repeller of the deviation oscillator is clamped to a predetermined negative value during each synchronizing pulse in a conventional manner. This clamping action enables the transmission of video signal components down to direct current. For message telephone transmission the clamping circuit is disabled.

The automatic frequency control circuit used to control the frequency of the beat oscillator provides a high gain and stable AFC without a d-c amplifier. As shown in Fig. 16, a portion of the 70-megacycle output signal is diverted and after passing through a gated amplifier is applied to a discriminator. The discriminator network is of conventional design and the detector elements are germanium diodes. The direct-current output voltages are applied to the grids of two triodes acting as a pulse modulator. The anodes of these triodes are supplied with a high level positive pulse used for gating from a blocking oscillator associated with the clamper circuit. This oscillator is free running for message signals but is triggered by the synchronizing pulses when video signals are being transmitted. The unbalance voltage on the triode grids controls the amplitude and polarity of the pulse produced by this modulator. After two stages of a-c. amplification this error signal is combined with a second high level pulse from the same blocking oscillator source in a phase detecting circuit, and, after integration, the d-c. output of this detector is used for AFC. With television operation the gated amplifier operates only during synchronizing pulses, and the discriminator is adjusted for an output frequency of 74 megacycles. With multi-channel message operation, the gated amplifier is operated as a straight-through amplifier, and the discriminator is adjusted to hold an average output frequency of 70 megacycles.

C. *FM Receiver*

The FM receiver contains an IF amplifier, limiter, discriminator, and video amplifier, as indicated in Fig. 17. The input amplifier consists of two stages, each using a 404A pentode, with broad-band interstage networks. The two-stage instantaneous amplitude limiter has biased silicon varistors shunting the single-tuned plate loads of each of the 418A tubes. The bias voltages are so adjusted that the load impedance is high for signal voltages less than about one volt, and very low for any larger signal.

1. *Discriminator*

The discriminator circuit follows early conventional practice, in that two separately driven antiresonant circuits are used. The signal at the limiter output is fed to two 404A amplifier stages, one tuned above the signal band,

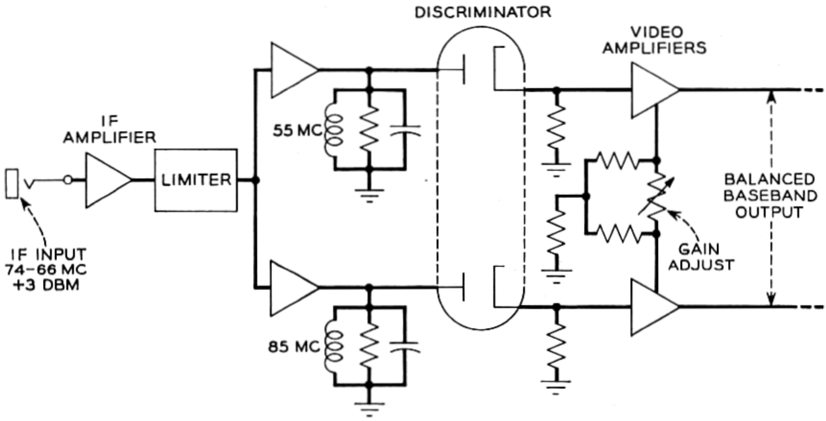


Fig. 17—Block diagram of FM terminal receiver.

the other below. The frequency-modulated signals produce amplitude variations of the voltage across these tuned circuits which are detected by diode rectifiers and applied to the video amplifier. A potentiometer in the cathode interconnection of the amplifier tubes provides a balance adjustment for the discriminator.

2. *Video Amplifier*

The video amplifier is a three-stage resistance-capacity coupled unit having negative feedback in each symmetrical half, and negative feedback to longitudinal voltages through a common cathode resistor. The gain is adjustable over a range of several db by means of a dual potentiometer which varies the common cathode resistance in each half of the amplifier. Whenever such an adjustment is made, a constant loop gain is maintained in the feedback system by varying simultaneously the local cathode degeneration in the middle stages of the amplifier. A peak-to-peak voltmeter connected across one side of the balanced output is used to monitor the transmission level of television signals.

V. System Maintenance and Test Equipment

A. *General*

Most TD-2 stations are operated on an unattended basis. Test equipment is provided at each terminal, auxiliary and main station to perform the necessary maintenance functions. This consists of a radio test bay as shown in Fig. 18 for each auxiliary, main and terminal station, and an FM test console as shown in Fig. 19 at terminals and main stations where FM terminal equipment is provided. The philosophy is to provide sufficient test equipment at each station to isolate the trouble. When the unit in trouble requires extensive tests or repair, a station spare is substituted and the faulty unit is returned to a maintenance center. Maintenance centers are usually located in existing telephone offices along the route.

In maintaining the radio equipment each repeater bay is adjusted to provide a transmission band 20 megacycles wide, flat to within two-tenths of a db and centered about the assigned channel frequency. Trimming adjustments are provided on the receiver and transmitter to obtain this characteristic. This test involves the use of a swept signal source which is divided into a reference path and a path through the equipment under test, each of which is terminated in an identical detector. The outputs of these detectors are alternately applied to the vertical deflection amplifier of an oscilloscope at a 30-cycle rate, while a voltage proportional to the frequency excursion is applied to the horizontal amplifier. Generally, the vertical gain of the oscilloscope is adjusted so that a separation of one inch between the test and reference traces corresponds to a level difference of 1 db and the horizontal gain is adjusted so that one inch corresponds to a 10-megacycle frequency excursion. The reference trace is then matched to the test trace by adjustments of the equipment under test. The waveguide attenuators and directional couplers shown in Fig. 18 provide for testing over a wide range of levels.

B. *Radio Test Bay*

The radio test bay contains a microwave swept frequency oscillator, a combined microwave and IF power meter, a cathode ray oscilloscope, RF and IF wave meters, detectors and attenuators and associated power supplies.

The microwave sweep oscillator is adjustable in sweep range up to 70 megacycles over the 3700 to 4200 megacycle band. The frequency is swept

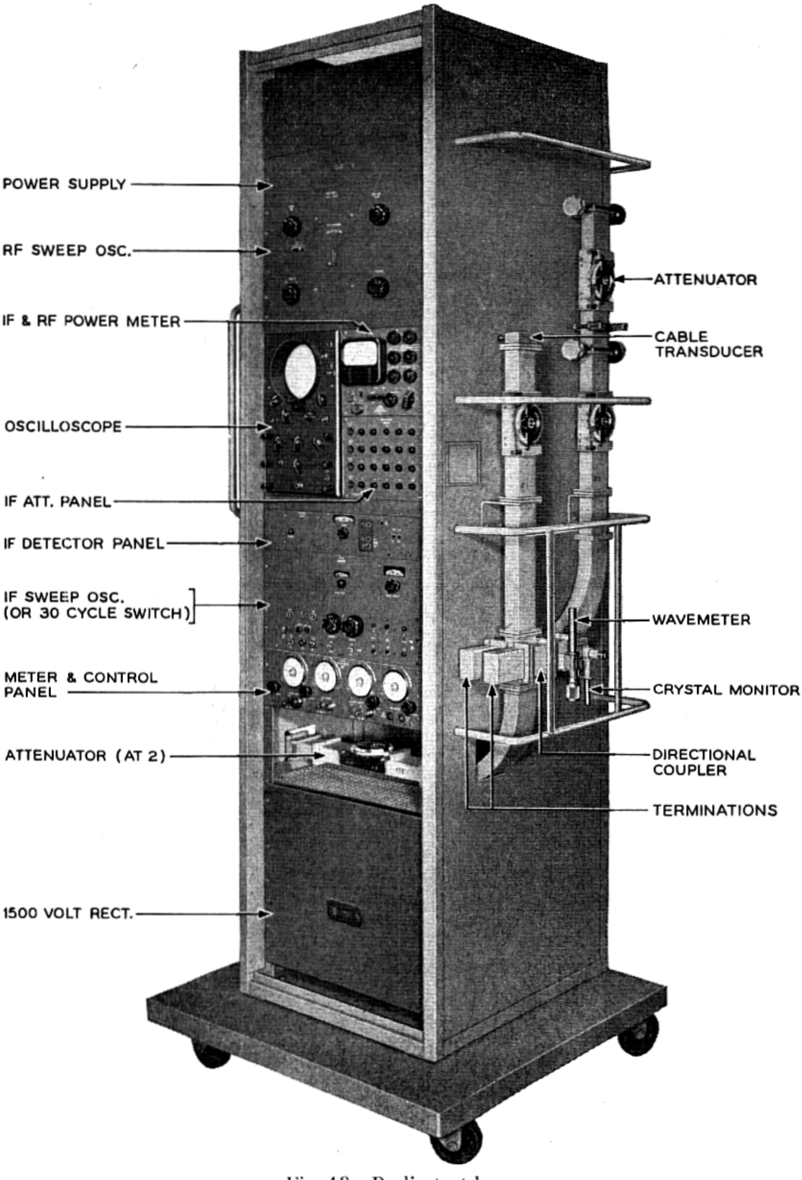


Fig. 18—Radio test bay.

by a motor driven reactive element in one of two cavities associated with the 402A velocity variation oscillator tube.

The RF and IF power meter consists of a temperature compensated thermistor bridge unit. It has separate input arrangements for the 3700 to 4200-megacycle and 50 to 90-megacycle bands. Accurate measurements of power may be made in the range from -10 dbm to $+6$ dbm.

The test bay used at maintenance centers has, in addition to the above equipment, a 50- to 90-megacycle swept frequency oscillator and associated detectors for the testing of intermediate frequency components. The operations carried out at the maintenance center include the repair and realignment of defective equipment returned from the radio stations. The maintenance center test equipment includes facilities for accurate impedance match measurement in the microwave and IF range, for varistor matching tests, vacuum tube transconductance tests and general component tests which cannot be made at the radio station. Usually the maintenance centers are operated by the same staff that maintains the radio stations in the section.

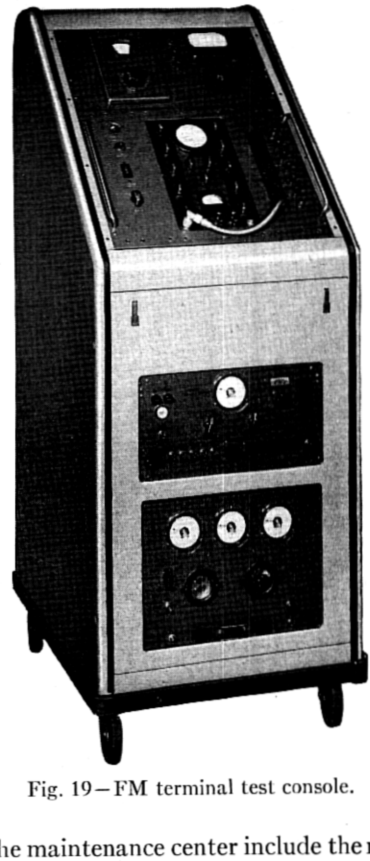


Fig. 19—FM terminal test console.

C. *FM Terminal Test Console*

The terminal test console shown in Fig. 19 is used to measure FM deviation, linearity of the FM transmitter and receiver and for routine monitoring of wave forms at video frequencies. The equipment includes a conventional CW signal generator covering the range of 50 to 90 megacycles, a video "A" scope, an electronic switch and patching and terminating facilities. A rather unique linearity test set described below and an FM terminal receiver are also included.

1. *Deviation Measurement*

For deviation measurements, the IF signal being monitored is patched into one input of the IF electronic switch which switches between inputs at a 1200-cycle rate, and the CW signal generator into the other input. After detection by the FM receiver, the signals are applied to the oscilloscope and a straight line corresponding to the CW generator frequency is displayed superimposed on the video signal. By adjustment of the CW reference frequency, the instantaneous frequency of any signal component may be determined.

2. *FM Receiver Linearity*

For a measurement of linearity of the receiver discriminator, the linearity test set is connected to an FM transmitter which is patched to the receiver under test. The linearity test set supplies a low level 100 kc modulating voltage to the deviation oscillator of the transmitter and a high level 60-cycle voltage to the transmitter beat oscillator. For this test the transmitter AFC circuit is disabled. Under these conditions the signal applied to the receiver discriminator swings over approximately 10 megacycles at a 60-cycle rate and over a small range of less than one megacycle at a 100 kc rate. The 100 kc video component in the receiver output is then proportional to the slope of the discriminator response curve. The envelope of this 100 kc amplitude is recovered in the linearity test set and the a-c. component is applied to the oscilloscope vertical amplifier. The horizontal deflection is synchronized with the 60-cycle deviation. A 30-cycle switch changes the amplitude of the 100 kc signal by a calibrated amount to provide two separated traces on the screen and make the device self-calibrating.

3. *FM Transmitter Linearity*

For a measurement of transmitter linearity, the same setup used in the receiver test is made use of except that both the 100 kc small signal and 60-cycle large signal are applied to the deviation oscillator of the transmitter under test. The beat oscillator AFC circuit is allowed to operate with a time constant sufficiently rapid to follow the 60-cycle fluctuation of the deviation oscillator, but not the 100 kc component. Thus the 100 kc modulation component is applied over a 10-megacycle range of the deviation oscillator characteristic, but is applied to the receiver at a fixed (70-megacycle) frequency, so that the receiver discriminator does not enter the measurement except as a fixed gain detector. While the transmitter is being tested as above, the magnitude and phase adjustments of the deviation oscillator load impedances are made as required to meet the desired linearity of deviation which is normally 1% over the 10-megacycle range.

VI. C1 Alarm and Control System*

The operation and maintenance of unattended repeater stations require a flexible and reliable alarm system whose performance is commensurate with the importance of the toll and television program services handled by the TD-2 System. The Cl alarm and control system has been developed for this purpose and, as its name implies, it serves two functions. The first is that of transmitting detailed alarm information from unattended repeater stations to the responsible alarm centers. The second function is that of transmitting orders, or remote control signals, from alarm centers to unattended stations.

The salient features of the C1 system may be summarized as follows:

1. It is a voice-frequency system, thus permitting its use with equal facility on cable pairs, open wire lines, or radio channels (or combinations thereof) capable of transmitting a 3000-cycle voice band.
2. It transmits a maximum of 42 separate alarms or indications from each unattended station to its associated alarm center.
3. It transmits a maximum of ten remote control orders in the opposite direction, that is, from an alarm center to each unattended station for whose operation it is responsible.
4. A maximum of twelve unattended stations may be associated with one alarm center.

A typical section of the TD-2 Radio Relay System is shown in Fig. 4. The alarm center for the section indicated is at Cuyahoga Falls, which in this case is also a maintenance center. Alarm centers and maintenance centers may be located at any attended central office or repeater station on existing cable and open wire routes.

Alarm signals are transmitted to the alarm center from the unattended station over a one-way, two-wire circuit as shown in Fig. 20. A four-wire local order circuit is used for voice communication between adjacent main radio stations and the intermediate unattended auxiliary repeater stations. The alarm centers and maintenance centers in that alarm section are also bridged on it. Remote control order signals from the alarm center are of such short duration that they can be transmitted without objectionable interference over one side of this four-wire local order circuit. An express

* Prepared by C. E. Clutts and G. A. Pullis.

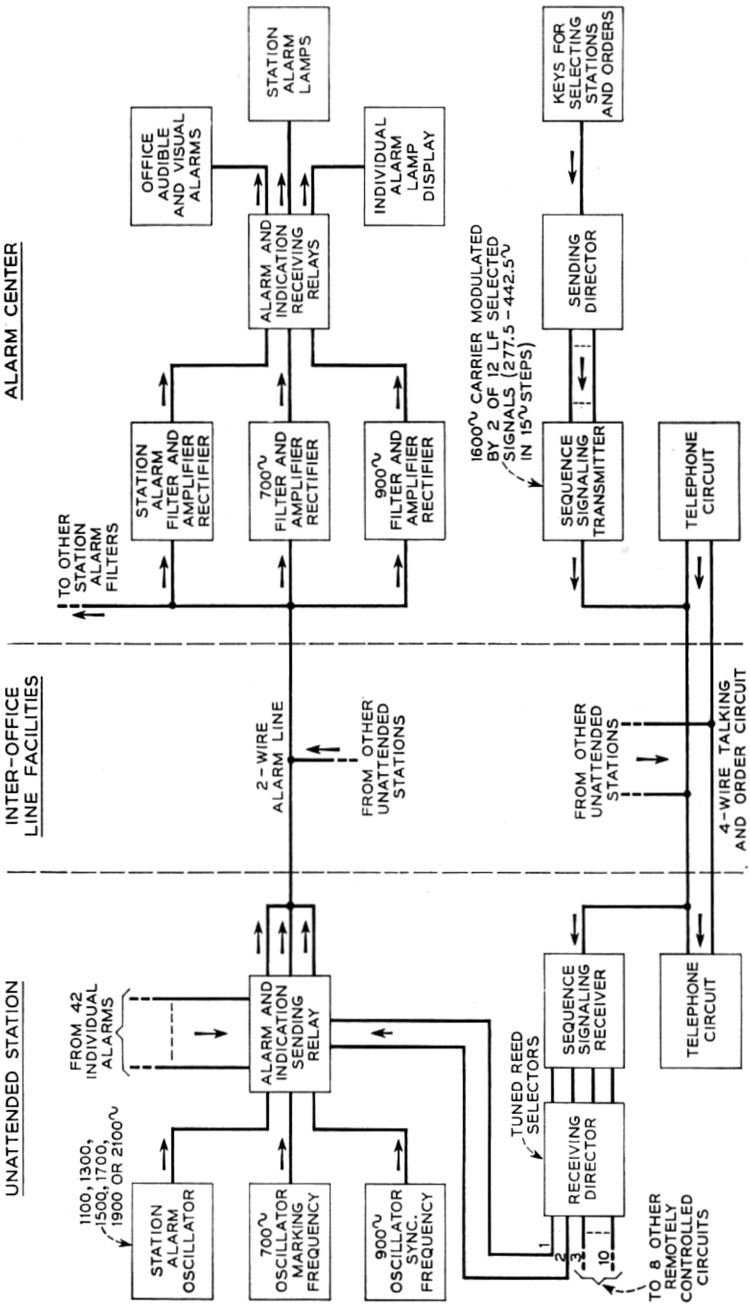


Fig. 20—Block diagram of CI alarm and control system.

order circuit is used to link the terminal stations of a system with the main stations, alarm centers and maintenance centers for system-wise radio maintenance and traffic control.

A. *Station Alarms*

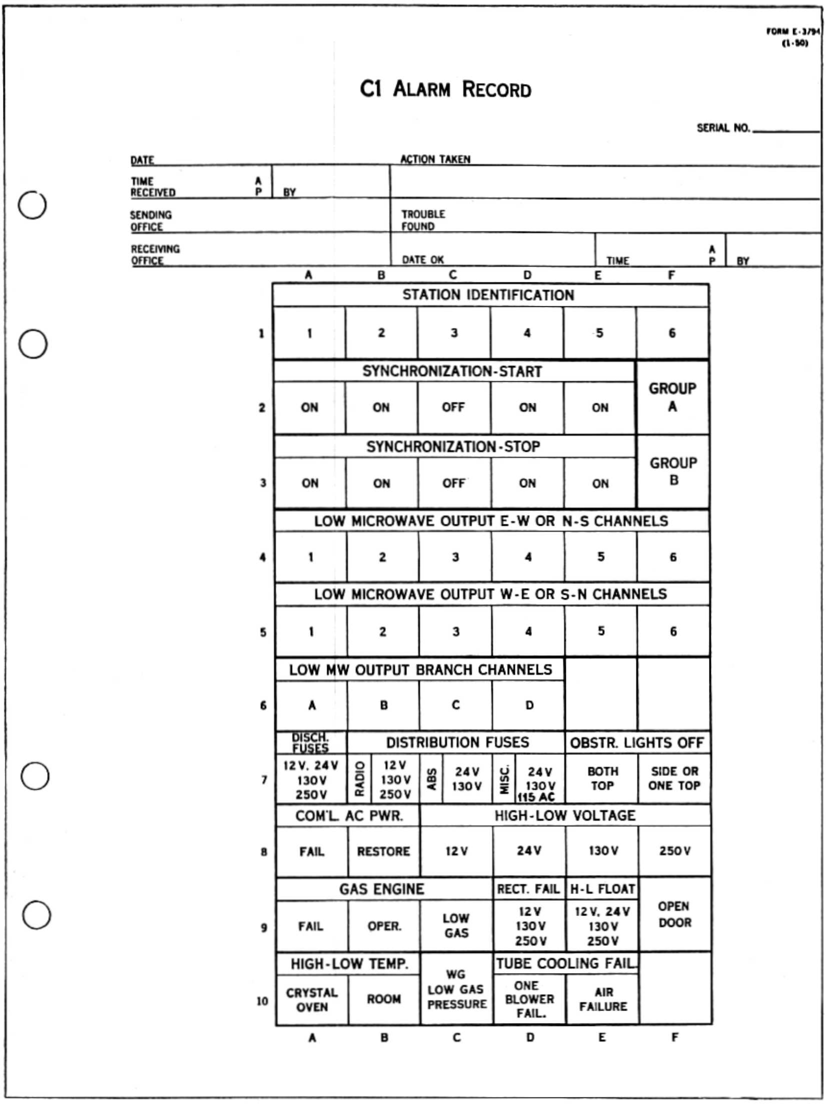
Each unattended station transmits a continuous and distinctive tone to its associated alarm center. Interruption of this tone for approximately ten seconds registers an audible and visual alarm at the alarm center, and, because each station is assigned a different frequency, the station whose tone is interrupted is easily identified. As many as six stations can report to an alarm center over a one-way, two-wire alarm line. Six more alarm sending stations can report to the same alarm center by bridging them on a second alarm line (usually in the opposite direction from the first), and providing a second set of receiving filters with associated amplifiers and detectors at the alarm center. In this manner an alarm center can identify the alarms from a maximum of twelve unattended repeater stations. The six station frequencies that can be used on one alarm line are 1100, 1300, 1500, 1700, 1900, and 2100 cycles.

Each station alarm tone is selected at the alarm center by its associated receiving filter and individual amplifier-rectifier circuit. Automatic gain control action in the amplifier circuit permits a tone from the alarm line to vary ± 6 db from its normal value without interfering with the proper operation of the system.

B. *Individual Alarm Indications*

The station alarm reports that a particular unattended point is in trouble, but it does not tell what the specific trouble is. Supplementing the station alarm circuit is an individual alarm indication circuit that reports which, if any, of 42 possible alarm conditions exist at an unattended station. The alarm indication sending circuit does not start automatically but only in response to an order sent out from the alarm center. Thus, after receiving a station alarm, an attendant at the alarm center sends an order over the control system described later to that particular station directing it to scan the individual alarms and report those that have operated.

The report is transmitted over the alarm pair and received on a miniature lamp bank located in the key shelf of the alarm receiving bay at the alarm center. Of a total of 60 lamps in the key shelf, 42 are used for alarm indications, 8 for identifying the six east or west reporting stations, and 10 for checking synchronization of the indication sending and receiving circuits. Figure 21 is a copy of the form which is placed over the lamp display to



FORM E-3794 (1-50)

C1 ALARM RECORD

SERIAL NO. ______

DATE ______ ACTION TAKEN ______

TIME RECEIVED ______ A P BY ______

SENDING OFFICE ______ TROUBLE FOUND ______

RECEIVING OFFICE ______ DATE OK ______ TIME ______ A P BY ______

	A	B	C	D	E	F
	STATION IDENTIFICATION					
1	1	2	3	4	5	6
	SYNCHRONIZATION-START					GROUP A
2	ON	ON	OFF	ON	ON	
	SYNCHRONIZATION-STOP					GROUP B
3	ON	ON	OFF	ON	ON	
	LOW MICROWAVE OUTPUT E-W OR N-S CHANNELS					
4	1	2	3	4	5	6
	LOW MICROWAVE OUTPUT W-E OR S-N CHANNELS					
5	1	2	3	4	5	6
	LOW MW OUTPUT BRANCH CHANNELS					
6	A	B	C	D		
	DISCH. FUSES	DISTRIBUTION FUSES			OBSTR. LIGHTS OFF	
7	12 V, 24 V 130 V 250 V	RADIO 12 V 130 V 250 V	ABS 24 V 130 V	MISC. 24 V 130 V 115 AC	BOTH TOP	SIDE OR ONE TOP
	COM'L. AC PWR.		HIGH-LOW VOLTAGE			
8	FAIL	RESTORE	12 V	24 V	130 V	250 V
	GAS ENGINE			RECT. FAIL	H-L FLOAT	
9	FAIL	OPER.	LOW GAS	12 V 130 V 250 V	12 V, 24 V 130 V 250 V	OPEN DOOR
	HIGH-LOW TEMP.			TUBE COOLING FAIL		
10	CRYSTAL OVEN	ROOM	WG LOW GAS PRESSURE	ONE BLOWER FAIL.	AIR FAILURE	
	A	B	C	D	E	F

Fig. 21 — Cl alarm record.

designate the lamps and provide a record of a specific alarm condition at an unattended station.

The alarm indication sending and receiving circuits utilize relay counting chains which scan over the 60 possible indications at a 5-cycle rate and cause a 900-cycle pulse to be sent back to the alarm center for each indication scanned. Whenever an alarm condition or other indication is encountered, a 700-cycle pulse is transmitted simultaneously with the 900-cycle pulse. At the alarm center the pulses are selected by 700- and 900-cycle filters, and amplified and detected in the same manner as the station tones. The resultant d-c. pulses operate relays which in turn light particular lamps in the key shelf lamp display panel in the alarm center receiving bay whenever the two pulses are received simultaneously.

C. *Sequence Signaling Remote Controls*

As mentioned earlier the C1 alarm and control system is capable of transmitting as many as ten orders from the alarm center to a particular station in trouble. Typical orders to a repeater station may be an order to scan all alarm indications or an order to start the gas engine alternator. Sequence signaling transmitters and receivers are employed for the transmission of orders to the unattended repeater stations. Sequence signaling is an arrangement in which two separate signals sent in a predetermined sequence are translated by the receiver into an order. One hundred and thirty-two different orders can be transmitted from an alarm center through sequence combinations of two out of twelve modulating frequencies available in 15-cycle steps from 277.5 to 442.5 cycles. The C1 system makes use of 120 of these orders at those alarm centers which remotely control as many as twelve unattended repeater stations.

An attendant initiates an order by operating the key of the station to be called, the proper order key and a start key. This operation selects the proper two low frequencies which modulate a 1600-cycle carrier oscillator and the sequence in which they are sent. The incoming signal to the sequence signaling receiver at an unattended station is amplified and demodulated. The two low-frequency tones recovered from the 1600-cycle carrier are applied sequentially to the receiving director. The director identifies the tones by means of four accurately tuned reed selectors, recognizes their sequence and translates them into one of ten orders for that particular repeater station.

VIII. Power Equipment*

The TD-2 System is supplied by battery voltages of -12, $+130$ and $+250$ volts maintained by charging rectifiers which float the batteries within limits of $\pm 1\%$. A 24 volt battery to supply power to the C1 alarm and order wire circuits is also included in the power plan where necessary. The block diagram illustrated in Fig. 22 shows the inherent simplicity of the plant. During power failures the batteries carry the load until an automatic gas

* Prepared by J. M. Duguid.

engine alternator or diesel alternator is warmed up and assumes the load, at which time floated operation is resumed. An important characteristic is the absence of any direct switching in the load leads during power failures. The control equipment in all three battery plants is arranged for full automatic operation and additional charging rectifiers are switched in and out as required. After a power failure the rectifiers operate at full capacity until the battery is recharged, after which normal floating operation is resumed. Sufficient capacity is normally installed to give at least an eight-hour reserve

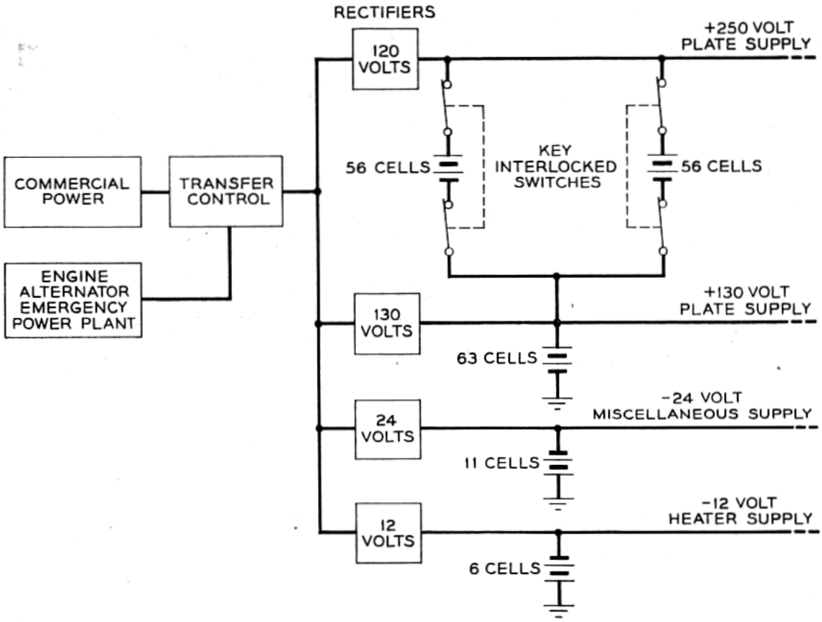


Fig. 22—Power plant block diagram.

to allow an attendant to get to the station in the event that the engine alternator fails to start.

A. −*12 Volt Supply*

The −12 volt heater supply consists of six battery cells floated by two or more parallel-connected 200-ampere full wave selenium rectifiers. The output voltage of the rectifier is controlled by a saturable reactor and regulating autotransformer in series with the primary of the stepdown power transformer which supplies the selenium bridge rectifier. The output voltage is automatically adjusted by the amount of d-c. current supplied to the saturable reactor by the electronic feedback control circuit in the rectifier. The battery is floated at 13 volts and a discharge resistor in each fused discharge lead is adjusted during installation to drop the voltage to the normal limits of 11.0 ± 0.1 volts at the radio bays. Under 60-cycle a-c. power failure conditions before the gas engine or diesel alternator accepts the a-c. load, the radio bays may operate between their emergency limits of 9.9 to 11.5 volts.

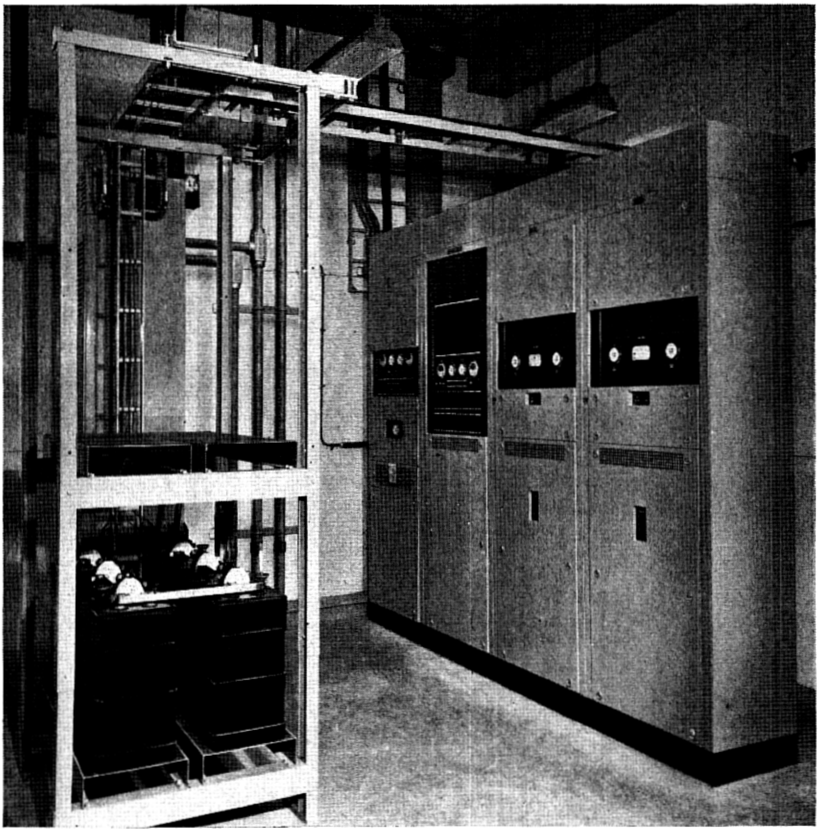


Fig. 23—12V and 24V power plant.

Figure 23 illustrates the installation in a typical tower of the −12 volt supply required for a main route of six radio channels in each direction.

B. *+130 Volt Supply*

The 130-volt plate supply consists of a 63-cell storage battery which is charged and floated by two to eight 8-ampere regulated tube rectifiers. As shown on Fig. 22, this battery serves as the lower section of the 250-volt plate supply. Its capacity of 20 amperes is sufficient to supply the combined 130 and 250 volt loads. The regulated rectifiers normally float the plate battery at a voltage of 136 ± 1%. Under a-c. power failure conditions emergency limits of 116 to 140 volts are permissible. Due to the relatively high voltage involved and in order to insure maximum service and personnel protection, the rectifiers and their associated control and distribution equipment are mounted in sheet metal enclosures as shown in Fig. 24.

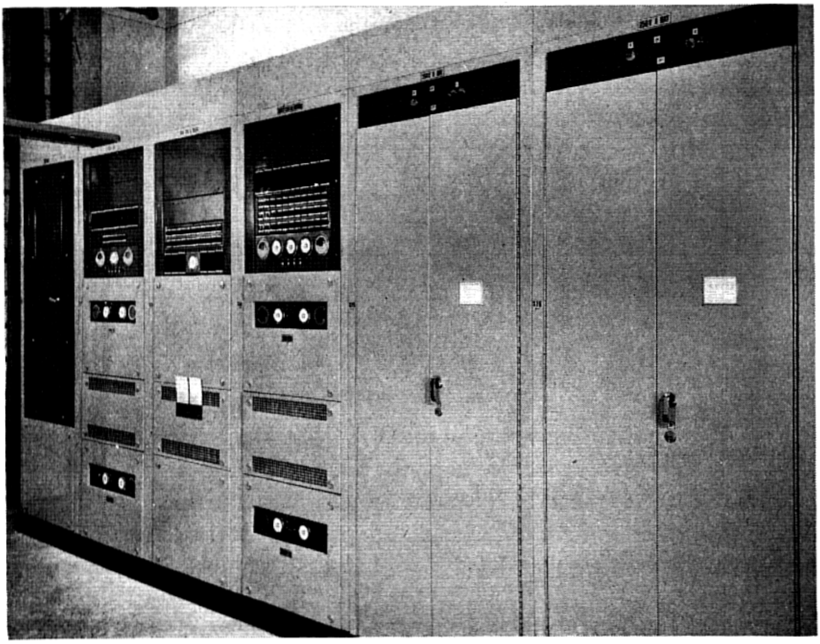


Fig. 24—130V power plant.

C. +*250 Volt Supply*

The 250-volt supply consists of duplicate 56 cell batteries in parallel which are in turn connected in series with the 63-cell 130-volt battery. Regulated thyratron rectifiers similar to those used in the 130-volt plate are connected across the 56 cells to float the load. The normal limits are 254 to 259 volts and the emergency limits are 224 to 266 volts. Each section of the 250-volt battery is housed in its own cabinet and key interlocked to protect maintenance personnel.

D. *−24 Volt Supply*

A −24 volt battery plant utilizing a regulated selenium charging rectifier capable of 6-ampere constant load supplies power for the alarm and order wire circuits. Voltage regulation is obtained by saturable reactors in a magnetic type of regulating circuit. This plant is shown as the extreme left bay in Fig. 23.

E. *Engine Alternator Reserve Plants*

The main route of the TD-2 system normally requires reserve engine alternators of 20 or 30 kw capacity. The initial sets used were of the automatic gasoline engine alternator type available in 20 to 60 kw capacity. The engines are fully automatic in operation. They accept the load after a predetermined period of commercial a-c. service failure and restore the load to the commercial service when it returns to normal. They are capable of long hours of operation under emergency conditions. Numerous alarms are available in the engine plant to indicate its status under all conditions. Recent development has made plants available similar to those mentioned above which are powered by automatic diesel engine driven alternators. It is expected that this latter type of engine will be used in the future where capacities of 20 kw or more are required.

VIII. Conclusion

The New York-Chicago section of the TD-2 transcontinental radio relay system was opened for service with the transmission of television network programs on September 1, 1950. The system was extended to Omaha on September 30, 1950. Similar systems were put into service during September between New York and Washington and between Los Angeles and San Francisco.

By the fall of 1951 a transcontinental microwave radio relay system will be in service between New York and San Francisco carrying television programs and hundreds of telephone messages. This system will augment present intercity toll facilities and, in conjunction with coaxial cable, will provide a nationwide network of broad-band channels capable of handling television transmission or large groups of telephone circuits.

The growth of broad-band channels during the next few years can be handled by the addition of channels to partially loaded TD-2 Systems and by new routes. Further expansion of radio relay systems into higher frequencies, 6,000 and 10,000 megacycle bands now set aside by FCC for common carrier use, appear to offer room for further expansion of systems comparable to TD-2.

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